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Soil Organic Carbon Storage, *N* Stock and Base Cations of Shade Coffee, Khat and Sugarcane for Andisols in South Ethiopia

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Abstract

In the Wondo Genet, Ethiopia, the common agricultural land uses include maize, shade coffee, khat and sugarcane. The objective of this study was to examine the impact of perennial land uses on soil organic carbon (*SOC*), soil *N* and base cations. Four sites having maize and one or two of perennial land uses and with similar site characteristics were identified for this study. Soils (0 - 30 cm) were sampled at corners of a plot (20 × 20 m^2) placed in each land use at each site. Results indicated that the *SOC* storage of the shade coffee plantations were 86% and 125% higher compared with adjacent maize land uses with the absolute differences being 50.7 and 54.4 $Mg \cdot ha^{-1}$, respectively. The soil *N* stock was 109% and 126% higher for the shade coffee than the maize land use while the absolute differences were 5.7 and 4.7 $Mg \cdot ha^{-1}$ for the same sites. Among perennials, the higher *SOC* storage in the shade coffee is attributable to the increased litter input and reduced soil disturbance in the system. While the higher soil *N* in the shade coffee was attributed to reduction of leaching, *N* uplift, and the increased litter quality and input. The high relative increase in shade coffee in *SOC* and soil *N* at Finance site was ascribed to the finer soil texture and low *SOC* and soil *N* at the compared adjacent maize farm. Although not significant, the relative increase in *SOC* (34%) and soil *N* (43%) in the sugarcane at the Finance as well as the relative increase in *SOC* (7%) and soil *N* (9%) in khat at Gotu as compared to Chaffee site was attributed to mainly the management differences. The shade coffee has the greatest potential for *SOC* storage and for increasing *N* stock, while khat and sugarcane have the least potential.

Keywords

Annual Maize, CEC, Perennial Crops, Soil Nitrogen, Wondo Genet

1. Introduction

The change of agricultural land to other land use types may lead to storage of *SOC* depending on the type of vegetation. Most agricultural soils have the ecological potential to sequester *SOC* above their existing levels [1]. This is because most soils in conventional agricultural ecosystems have lost *SOC* (also nutrients along with *SOC*) from their antecedent *SOC* pool [2] [3]. Soil disturbance through tillage is a major cause of reduction in the number and stability of soil aggregates, and subsequently, *SOC* depletion [4]. However when conventional agricultural land use type is changed to other agricultural land use types, it will lead to change in the quality and quantity of residue inputs. The change in residues depends on the productivity and the management of the vegetation replacing the annual crops [5]. Depending on residue input and management of the replacement vegetation, there is a large variation in magnitude and length of time that *SOC* may accumulate. Reduced soil disturbance through tillage decreases the rate of *SOC* mineralization [6] and increases *SOC* storage. *SOC* storage in agricultural soils has the greatest potential to mitigate climate change in sub Saharan Africa agriculture [7], and to increase agricultural productivity [2].

Conversion of annual agriculture to plantation forests is shown to increase soil nutrients levels and sequester *SOC* [8] [9]. Other studies have also investigated the effect of agricultural management systems such as nutrient management, no till, and mulch tillage on *SOC*, and found that *SOC* increased under these systems when compared with conventional agriculture [2] [10]. This increase is attributed to the improved organic matter input and/or reduced negative impact of tillage in these agricultural managements. Conversion of annual agriculture to perennial grasses results in increased *SOC* compared to agricultural soils [11]. These conversions contribute to soil fertility replenishment as well as climate change mitigation. However, few studies have examined the impact of perennial crops, particularly in low input tropical agricultural systems.

In southern Ethiopia's Wondo Genet Woreda, agricultural land use has been changing over the last three decades. Studies by [12] showed that the number of farmers growing annual crops such as maize (*Zea mays* L.) decreased significantly between 1985 and 2002. During the same period, the number of farmers who grew khat (*Catha edulis* F.) and sugarcane (*Saccharum officinarum* L.) increased. This trend has continued to the present and resulted in the dominance of khat and sugarcane in the landscape. The presence of simultaneous cultivation of maize along with khat and sugarcane as well as the presence of some coffee (*Coffea arabica* L.) farms in the area provide an opportunity to study the effect of these perennial crops on soil properties by comparing with strictly maize cultivation. Thus the objective of this study was to examine the effect of perennial land uses on *SOC*, Soil *N* and base cations.

2. Methods

2.1. Study Area

Wondo Genet Woreda is located 273 km south of Addis Ababa in southern

Ethiopia at 7˚4'30" and 7˚7'30"N latitude and 38˚33'30" and 38˚39'0"E longitude (**Figure 1**). It is one of the most densely populated areas in Ethiopia with over 588 people·km^{-2}. Most of the agricultural lands are found in the same agro climatic zone, and situated between elevations 1700 and 1900 m a.s.l. At the higher elevations (>2000 m a.s.l.) there are steep grassy slopes, bush cover and remnants of degraded forest. The area has a bimodal rainfall pattern with mean annual rainfall of 1240 mm. The mean annual temperature is 19.5˚C. The soils are Andisols [13]. The underlying parent materials are of alkali trachytes and basalts, often overlain by volcanic ash deposits from the late tertiary volcanic period [14].

The farming system consists of mixtures of annual crops (maize) and perennials (shade coffee, khat and sugarcane). *Coffee arabica*, which is native to Ethiopia, is the world's most widely traded tropical agricultural commodity. Shade trees offer several advantages for coffee cultivation, including temperature regulation and weed suppression [15]. Khat, a mild stimulant, is an evergreen plant that grows mainly in Ethiopia, Yemen and other African countries along the Indian Ocean. Sugarcane is commonly cultivated by many Ethiopian smallholder farmers for household consumption (chewing and sucking the juice) and income generation.

2.2. Soil Sampling

Since land use types were not uniformly distributed, we looked for the sites with maize and at least one adjacent perennial land use. Accordingly, Gotu, Wondo Genet College campus (WGCC), Finance and Chaffee were identified for this study. The selected land uses at each site had similar site properties and land use history. The study sites information, including land use history and present management, is shown in **Table 1**.

Soil samples were collected in April 2013 from the four corners of a square plot (20 m × 20 m) located randomly in each cropland use at each site [3]. *SOC* is generally concentrated in the top 30 cm of the soil and so land use change is generally expected to have the greatest impact on *SOC* in these upper layers [16]. Thus, soils were sampled at 0 - 30 cm soil depth using a core sampler (diameter = 7.2 cm). A total of forty soil samples were taken from all the agricultural land uses. Soil cores in the sugarcane were taken from a position that was vertically half way between the top of the ridge and bottom of the furrow. All soil samples were air-dried at room temperature, and then sieved (2 mm mesh).

2.3. Soil Analysis

Soil pH was determined potentiometrically in a 1:2.5 (v/v) soil: water suspension. Dry bulk density was calculated by dividing the oven dry mass at 105˚C of the <2 mm fraction, by the volume of the core. Volumes of gravel were taken into account, but made up <4% in most of the samples. The soil particle size distribution was determined using the hydrometer method [17]. Exchangeable

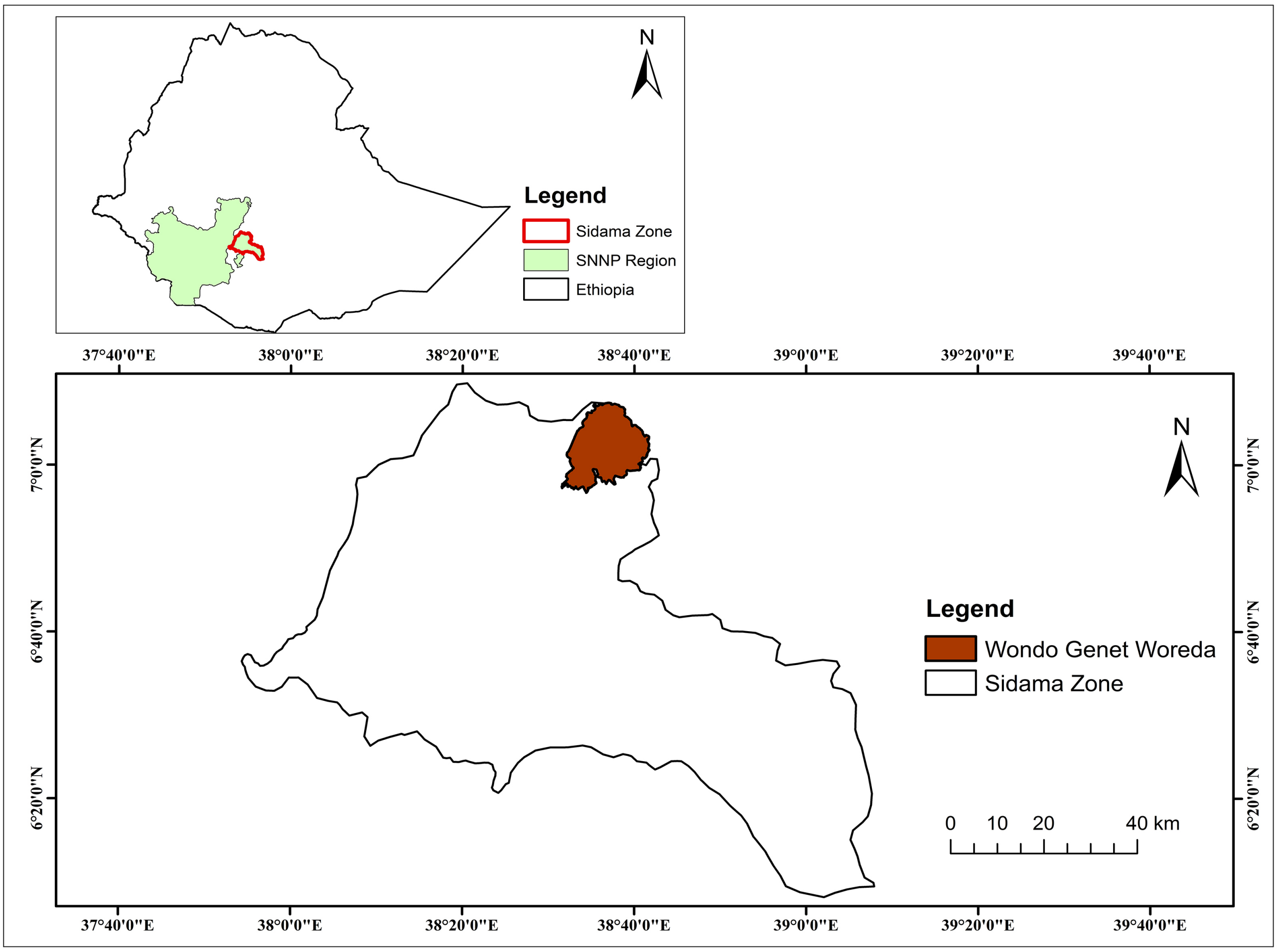

Figure 1. Location map of the study area.

bases (Ca^{2+}, Mg^{2+} and K^+) and cation exchange capacity (CEC) were analyzed in 1 M ammonium acetate extract at pH 7. The concentrations of Ca^{2+}, Mg^{2+} and K^+ in the extract were analyzed by atomic absorption spectroscopy (AAS). CEC was estimated titrimetrically by distillation of the displaced ammonia [18]. *SOC* was measured by the Walkley-Black method [19] and soil *N* was measured by the Kjeldahl method [20].

2.4. Calculations of Stocks and Relative Variation of *SOC* and Soil *N*

SOC and total soil *N* concentrations in 0 - 30 cm soil depth were converted to an area basis ($\text{mass}\cdot\text{ha}^{-1}$) according to the following equations [21] [22]:

$$SOC = Cz\rho_b 10 \quad (1)$$

$$\text{Soil } N = Nz\rho_b 10 \quad (2)$$

where C = the soil organic C concentration ($\text{g}\cdot\text{kg}^{-1}$), z = thickness of the sampled soil layer (m), ρ_b = bulk density ($\text{Mg}\cdot\text{m}^{-3}$), SOC = the amount of soil organic C stock($\text{Mg}\cdot\text{ha}^{-1}$), N = the soil nitrogen concentration ($\text{g}\cdot\text{kg}^{-1}$)and soil N = the amount of soil nitrogen stock ($\text{Mg}\cdot\text{ha}^{-1}$).

Table 1. Site information, management and site history of land uses.

Site and site information	Land uses	History and management of the agricultural land uses
Wondo Genet College campus (WGCC) Situated at N07˚06.285 and E038˚37.140, elevation-1757 m a.s.l,	Maize (*Zea mays*)	Ploughed by a tractor; fertilized (100 kg·ha^{-1} urea; 150 kg·ha^{-1} DAP); maize was the predominant crop; cultivated since 1954 after forest clearing; most crop residues were removed.
	Coffee, (*Coffea arabica*).	Shade trees, mainly *Cordia africana* and *Albizia gummifera* (60%) and 14 other shade tree species; the coffee bush density is 2500 plants·ha^{-1}; no fertilization or manure application; weed slashed once a year; stumped twice; coffee berries were harvested (hand-picked) every year; has been under coffee since 1950 after forest clearing.
Gotu Smallholder farmland, situated at N 07˚05.303 and E038˚38.158N, elevation-1873 m a.s.l,	Maize	Traditional farming ploughed by oxen; fertilized (DAP ~20 kg·ha^{-1}); maize was the predominant crop; cultivated for more than 20 years; most crop residue removed.
	Khat	FYM (~7 t·ha^{-1}) is applied; leaf parts harvested two to three times a year, the khat field that had been under maize cultivation was converted to khat after 1992.
Finance Smallholder farmland, Situated at N 07˚06.003 and E038˚36.758, elevation-1731 m a.s.l,	Maize	Traditional farming ploughed by oxen; fertilized (DAP ~20 kg·ha^{-1}); has been predominantly under maize production for more than 30 years; most crop residue removed.
	Coffee	Coffee plantation with shade tree, *Cordia africana,* 125 trees·ha^{-1}; Coffee plant density 2500 trees·ha^{-1}; no fertilization or FYM; no planned weeding; coffee berries harvested (hand-picked) every year; Part of field under maize cultivation was converted to this coffee plantation after 1982.
	Sugar cane	Land prepared by hoe for planting sugarcane; sugarcane at the middle of the rotation; fertilizer(DAP ~15 kg·ha^{-1}) and FYM (~7.5 t·ha^{-1}) applied; trash used for animal feed; irrigated; harvested every 18 months; Part of field under maize cultivation was converted to this sugarcane plantation after 1984.
Chaffee Smallholder farmland, situated at N 07˚04.430 and E038˚35.612, elevation-1700 m a.s.l,	Maize	Traditional agriculture ploughed by oxen; fertilized (DAP ~20 kg·ha^{-1}); has been under maize cultivation since before 1988; most crop residue removed.
	Khat	FYM applied (~4.5 t·ha^{-1}), leaf parts harvested twice a year, the land was under maize cultivation and was converted to khat after 1988.
	Sugar cane	Land prepared by hoe for planting sugarcane; sugarcane close to harvest; Land prepared by hoe; FYM applied (~4.5 t·ha^{-1}); trash used for animal feed; irrigated; harvested every 18 months; the land had been under maize cultivation before 1988.

Relative coefficient for the variation in *SOC* and soil *N* stock across agricultural land uses were computed by taking the maize land use as a reference [23]. Hence the relative coefficient for *SOC* and soil *N* stock expresses how much increased or decreased in relation to the maize land use.

$$RC_{(SOC\ \text{or soil}\ N\ \text{stock})pm} = (Vp - Vm)/Vm \tag{3}$$

$$\%RC_{(SOC\ \text{or soil}\ N\ \text{stock})pm} = RC_{(SOC\ \text{or soil}\ N\ \text{stock})pm} \times 100 \tag{4}$$

where $RC_{(SOC\ \text{or soil}\ N\ \text{stock})pm}$ = relative coefficient of *SOC* or soil *N* stock of perennial land use with respect to maize land use; V_P = *SOC* or soil *N* stock of perennial land use and V_m = *SOC* or soil *N* stock of maize.

2.5. Statistical Analysis

All data were analyzed using SPSS 16.0 statistical software. One way analysis of variance (ANOVA) was used to compare the soil parameters (e.g. *SOC*, soil *N*, base cations, CEC) for each site separately. Assumption of equality of variance was tested using Leven's test. Significant results from ANOVA at $P < 0.05$ were followed by Tukey's HSD *post hoc* separation.

3. Results

3.1. Soil Properties: pH, Bulk Density and Texture

The soil pH of shade coffee was significantly higher ($P < 0.01$) than that under maize at WGCC while the soil pH of the sugarcane was significantly lower ($P < 0.05$) than the maize at Finance (**Table 2**). Bulk density of shade coffee was significantly lower ($P < 0.05$) than that under maize while bulk density of sugarcane and khat did not differ ($P > 0.05$) from that under maize (**Table 2**). The particle size distribution and texture of the soils are shown in **Table 2**. The soils at Wondo Genet College campus (WGCC) and Gotu had a sandy loam texture and those of Finance and Chaffee a loam texture.

3.2. Soil Carbon

SOC concentration ($g \cdot kg^{-1}$) of khat and sugarcane was not significantly different ($P > 0.05$) from adjacent maize land. Shade coffee contained significantly higher ($P < 0.001$) *SOC* concentrations as compared to adjacent maize land in each studied site (**Table 3**). As expected, the differences in *SOC* stock ($Mg \cdot ha^{-1}$; **Table 3**) among agricultural land uses were similar to that of *SOC* concentration ($g \cdot kg^{-1}$). Shade coffee had 50.6 $Mg \cdot ha^{-1}$ more *SOC* compared with the adjacent maize at WGCC while it had 54.4 $Mg \cdot ha^{-1}$ more compared with that of the adjacent maize at Finance. The relative increase in *SOC* stock in shade coffee at the Finance site was high (125%) when compared with the increase at WGCC (86%).

In general, when comparing the effect of different perennial crops with annual maize, *SOC* stock increased in shade coffee in both sites (**Figure 2**). Though not significant, the relative increase in *SOC* in sugarcane at Finance was 34% while relative decrease of 14% was observed at Chaffee when compared with annual maize (**Figure 2**). The relative increase in *SOC* in Khat at Gotu and Chaffee was 7% and 4%, respectively (**Figure 2**).

3.3. Soil Nitrogen

Soil *N* concentration ($g \cdot kg^{-1}$) and soil *N* stock ($Mg \cdot ha^{-1}$) in the shade coffee were significantly higher ($P < 0.01$) than those in the maize. Soil *N* concentration and

Table 2. Mean (SE) soil pH, BD, particle size distributions and textural classes under annual and perennial agricultural land uses.

Site	Land uses	pH	BD (g/cm^3)	Sand	Silt	Clay	Texture
WGCC	*Maize*	5.4 ± 0.1a	1.0 ± 0.05a	52.5 ± 1.7	35.7 ± 0.8	11.9 ± 0.9	Sandy loam
	Coffee	6.1 ± 0.2b	0.8 ± 0.01b	54.9 ± 4.6	37.5 ± 5.0	7.6 ± 1.3	Sandy loam
Gotu	*Maize*	6.6 ± 0.2a	0.8 ± 0.01a	56.5 ± 2.6	33.2 ± 1.5	10.3 ± 2.9	Sandy loam
	Khat	6.9 ± 0.1a	0.8 ± 0.02a	67.6 ± 2.0	25.9 ± 1.0	6.5 ± 1.1	Sandy loam
Finance	*Maize*	6.8 ± 0.1a	1.0 ± 0.03a	50.4 ± 4.3	36.7 ± 3.3	12.9 ± 1.1	Loam
	Coffee	6.7 ± 0.1a	0.8 ± 0.01b	47.6 ± 4.4	40.5 ± 2.7	11.9 ± 2.0	Loam
	Sugarcane	6.2 ± 0.1b	1.0 ± 0.03a	47.4 ± 2.7	36.8 ± 1.7	15.7 ± 1.4	Loam
Chaffee	*Maize*	6.3 ± 0.2a	0.9 ± 0.01ab	45.6 ± 2.0	35.5 ± 2.7	18.8 ± 0.9	Loam
	Khat	6.5 ± 0.1a	0.8 ± 0.02a	50.0 ± 2.6	36.1 ± 2.0	14.0 ± 1.2	Loam
	Sugarcane	6.6 ± 0.1a	0.9 ± 0.02b	46.6 ± 1.0	38.3 ± 2.1	15.1 ± 1.1	Loam

*Values for crop types at each site with the same letters in columns are not significantly different.

Table 3. Mean (SE) *SOC*, soil *N* and C/N ratio, exchangeable bases and CEC under annual maize and perennial land uses.

Site	Crop type	C ($g \cdot kg^{-1}$)	N ($g \cdot kg^{-1}$)	C/N	C ($Mg \cdot ha^{-1}$)	N ($Mg \cdot ha^{-1}$)	Exchangeable bases ($cmolc \cdot kg^{-1}$)			CEC
							Ca^{++}	Mg^{++}	K^{+}	
WGCC	*Maize*	20.6 ± 5.2a	1.8 ± 0.4a	11.4 ± 0.9a	58.9 ± 12.6a	5.2 ± 0.9a	10.9 ± 1.3a	5.9 ± 0.9a	0.6 ± 0.2a	20.1 ± 2.1a
	Coffee	44.6 ± 5.2b	4.4 ± 0.5b	10.1 ± 0.7a	109.5 ± 11.9b	10.9 ± 1.0b	16.5 ± 3.7a	3.6 ± 0.4a	1.8 ± 1.1a	28.8 ± 2.3b
Gotu	*Maize*	30.2 ± 0.9a	2.8 ± 0.2a	11.4 ± 0.7a	74.2 ± 0.6a	6.9 ± 0.5a	14.6 ± 1.1a	2.8 ± 0.4a	0.6 ± 0.1a	19.2 ± 1.5a
	Khat	32.6 ± 8.0a	3.1 ± 0.7a	10.5 ± 0.5a	79.1 ± 17.2a	7.5 ± 1.5b	16.9 ± 1.2a	5.1 ± 0.6b	1.8 ± 0.5b	24.5 ± 1.6a
Finance	*Maize*	15.1 ± 1.6a	1.3 ± 0.1a	11.6 ± 0.7a	43.5 ± 4.8a	3.7 ± 0.3a	8.8 ± 1.2a	3.9 ± 0.6a	3.9 ± 0.6a	15.8 ± 1.2a
	Coffee	40.2 ± 1.2b	3.4 ± 0.2b	11.8 ± 0.9a	97.9 ± 6.7b	8.5 ± 0.5b	16.4 ± 1.4b	4.4 ± 0.7a	3.0 ± 0.8a	27.1 ± 4.9b
	Sugarcane	20.1 ± 0.8a	1.8 ± 0.2a	10.6 ± 0.6a	58.5 ± 6.4a	5.4 ± 0.6a	14.2 ± 0.8b	3.0 ± 0.8a	1.0 ± 0.1b	19.1 ± 1.1a
Chaffee	*Maize*	24.7 ± 1.4a	2.3 ± 0.2a	10.7 ± 0.6a	62.5 ± 3.1a	5.9 ± 0.4a	13.6 ± 1.0a	4.0 ± 0.8a	1.0 ± 0.1a	22.4 ± 1.1a
	Khat	26.7 ± 4.1a	1.7 ± 0.5a	10.4 ± 1.0a	65.1 ± 10.4a	5.5 ± 0.4a	11.8 ± 0.6a	4.2 ± 1.5a	1.1 ± 0.1a	26.4 ± 2.4a
	Sugarcane	20.7 ± 0.6a	2.0 ± 0.3a	11.4 ± 1.7a	56.1 ± 2.7a	5.3 ± 0.8a	13.3 ± 0.1a	5.3 ± 2.0a	0.7 ± 0.1b	24.3 ± 2.1a

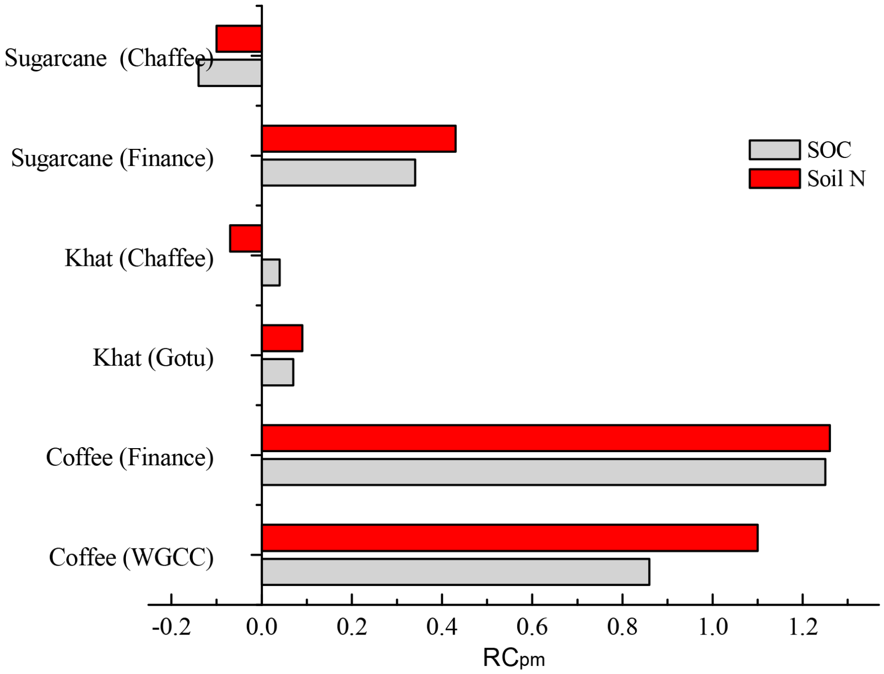

Figure 2. Relative coefficient (RC) for the variations of *SOC* and Soil *N* stock in perennial land use as compared with maize land use at each site.

soil *N* stock did not differ ($P > 0.05$) between khat and maize (Table 3). Similarly soil *N* ($g \cdot kg^{-1}$) and soil *N* ($Mg \cdot ha^{-1}$) soils did not significantly differ ($P > 0.05$) between maize and sugarcane. Shade coffee had 5.7 $Mg \cdot ha^{-1}$ higher amount of soil *N* compared with maize at WGCC and the corresponding figure for Finance site was 4.7 $Mg \cdot ha^{-1}$. The relative increase in soil *N* stock under shade coffee at the Finance site was high (126%) when compared with the increase at WGCC (109%). Though not significant, the relative increase in soil *N* in sugarcane at Finance was 43% while relative decrease of 14% was observed at Chaffee when compared with annual maize (Figure 2). The relative increase in Soil *N* in Khat at Gotu was 9% while the relative decrease at Chaffee was 7% (Figure 2). *C*/*N* ratio of the perennial agricultural land uses was not significantly different from the annual maize cultivated sites (**Table 3**).

3.4. Exchangeable Bases and CEC

All perennial land use types did not differ in exchangeable Mg^{2+} from that in the annual maize except for significantly higher ($P < 0.05$) exchangeable Mg^{2+} in the khat at Gotu (**Table 3**). The perennial land use types did not differ in exchangeable Ca^{2+} from that of annual maize except for the significantly higher ($P < 0.05$) exchangeable Ca^{2+} in the shade coffee and sugarcane at the Finance site. Maize had higher ($P < 0.05$) exchangeable K^+ levels than sugarcane. CEC of soils in the shade coffee was significantly higher ($P < 0.01$) than that under maize. There was no significant difference in CEC between maize and khat as well as between maize and sugarcane.

4. Discussion

4.1. Soil Organic Carbon

In this study *SOC* for the shaded coffee plantations was higher than the adjacent maize. The *SOC* concentration of shade coffee was also in the upper margin of the reported *SOC* content for coffee [24]. In the study area plant parts are not removed from shade coffee except for the coffee berries (**Table 1**). Hence the difference in *SOC* between shade coffee and maize could have originated from litter inputs from coffee plants and shade trees. Large litter productions by trees have been demonstrated by some studies in Ethiopia. Litter fall study in south Ethiopia indicated that coffee trees produced 0.5 $Mg \cdot ha^{-1} \cdot yr^{-1}$ whereas shade trees produced 1.7 to 5.3 $Mg \cdot ha^{-1} \cdot yr^{-1}$ [25]. Another study from south western Ethiopia displayed exotic trees litter input in a range of 8.9 - 10.8 $Mg \cdot ha^{-1} \cdot yr^{-1}$ [21]. A litter fall study in north Ethiopia showed tree litter inputs in the range of 0.3 - 4.25 $Mg \cdot ha^{-1} \cdot yr^{-1}$ in area ex-closures [26].

Studies have demonstrated the importance of litter input on *SOC* buildup. Soil amended with crop residue contained twice the *SOC* than soil with residue removal over 15 years in Nigeria [27]. The application of 3 $Mg \cdot ha^{-1} \cdot yr^{-1}$ dry matter of *Leucaena leucocephala* mulch in Kenyan coffee plantations over a 3-year period lead to a 15% increase in *SOC* concentration [28]. A hierarchical analysis of published articles indicated that crop residue retention of 1.5 to 2.5 $Mg \cdot Cha^{-1} \cdot yr^{-1}$ or higher increased *SOC* by 50% in arid climates while almost doubling in equatorial climates [29]. High *SOC* has been reported in shade coffee as compared with un-shaded coffee plantations [30] [24] Sadeghian *et al.* 2001 as cited in [31]. This difference between shade coffee and un-shaded coffee plantations may also corroborate the importance of litter input from shade trees. This assertion was verified by a Costa Rican study that showed the annual shade coffee litter fall, measured as dry weight, was 4.5 $Mg \cdot ha^{-1} \cdot yr^{-1}$ higher than in the un-shaded coffee [32].

The reduced soil disturbance in the shade coffee when compared to maize could have also contributed to the *SOC* storage. The result of a global analysis of

67 long term studies, [33] showed that most cropping systems changing from conventional tillage to no tillage could result in sequestration of 0.57 ± 0.14 Mg $C \cdot ha^{-1} \cdot y^{-1}$. This is caused by a reduced rate of *SOC* mineralization [6] and most likely occurred in the first 10 years after changing the tillage practice [33]. In Malawi, conversion of conventional tillage in smallholder farms to no till resulted in a 75% increase in *SOC* and a 77% increase in soil *N*, just 5 years after conversion [34]. Increasing *SOC* storage in the shade coffee system may contribute towards the mitigation of rising greenhouse gas emissions.

The lack of difference in *SOC* between khat and maize as well as sugarcane and maize maybe explained by the removal of plant parts/residues in khat and sugarcane management [5]. In khat production, a large percentage of fresh leaves were removed during the 2 to 3 per-year harvests (**Table 1**) thereby reducing the potential soil organic matter input. With sugarcane, every 18 months, the sugarcane plant is harvested including the tops (**Table 1**), which are used as animal feed. Sugarcane can produce residues in the range 13 - 20 $t \cdot ha^{-1}$ [35], but removing, instead of retaining residues, hastens *SOC* decline [10]. Farmyard manure amendment resulted in greater *SOC* when compared with the same system without manure [36]. The application of farmyard manure (FYM) at rates of 4 - 12 $t \cdot ha^{-1}$, which comprises application rates in the present study, produced average grain yields in Ethiopia [37]. Therefore the amount of applied farmyard manure may not be sufficient to influence *SOC* beyond the level of the annual maize.

4.2. Soil Nitrogen

The mean soil *N* stock was higher for the shade coffee plantations by 5.7 $Mg \cdot ha^{-1}$ and 4.7 $Mg \cdot ha^{-1}$ as compared to the soils of maize farms. In general, soil *N* varied between different land uses in the same way as *SOC* which is expected due to the close association between *C* and *N* in the soil [22]. The coffee plant's fine roots are found in the first 20 to 30 cm soil depth [38], and when complemented with shade trees, the potential loss of *N* via leaching below the shallow coffee roots can be reduced [39]. *N* uplift by shade trees can explain the increase in total *N* in the shade coffee. An average of 155 - 210 $kg \cdot ha^{-1}$ nitrate *N* has been found in sub soils (50 - 200 cm· depth) in western Kenya [40], where the maize is unable to access this nitrate pool because of shallow root depth. Thus, *N* cycling by shade trees may contribute to the higher soil *N* in surface soil layer under coffee. However, soil *N* might also have been lost to a greater extent through harvest and through leaching under maize, sugarcane and khat. [39] found higher *N* mineralization rates under shade coffee in comparison to an un-shaded coffee plantation. These findings may imply that substrate quality and quantity have increased in shade coffee, which may recycle *N* to soils under shade coffee via natural litter fall.

Maize residue has poor quality with low *N* concentration and wide *C*-to-*N* ratio [41]. However [41] has shown that increased level of *N*-fertilizer has increased the magnitude of *N*-mineralization rate of the maize residues. In the present study, large proportions of maize residues were removed while low level *N* fertilizer (except at WGCC) was applied to the annual maize (**Table 1**), which may restrict *N* availability in annual maize soils.

4.3. Relative Variations of *SOC* and Soil *N*

The relative variations in *SOC* and soil *N* between the shade coffees may have occurred due to different factors. The higher increase in *SOC* storage at Finance than WGCC site may be attributed to Finance's finer soil texture. Texture is an important determinant of the *SOC* storage capacity, as higher clay fractions correspond with higher *SOC* content. The finer soil particles play a central role in the *SOC* dynamics by promoting the formation of organic mineral complexes, which stabilize *SOC* and influence the physical protection of *SOC* within soil aggregates [42] [43]. Furthermore, finer soil particles enhance water retention in soils and promote biomass production which increases the litter input to the soil [44]. Besides, the relatively low *SOC* in the adjacent maize may have contributed to higher relative increase in the shade coffee at Finance. The potential of *SOC* sequestration is high in agricultural soils which have lost a significant part of their original *SOC* [2]. The relatively higher increase in the shade coffee soil *N* at the Finance site can be due to the low soil *N* in Finance's adjacent control maize, compared to WGCC.

Though the differences in *SOC* and soil *N* were not significant between khat and maize as well as sugarcane and maize, the relative coefficients for *SOC* and soil *N* in khat and sugarcane differed between sites. The high relative increase in *SOC* and soil *N* in the sugarcane at Finance as well as in khat at Gotu compared to those of the Chaffee site may be attributable to the management difference between sites (**Table 1**). In sugarcane at finance and in khat at Gotu, a higher rate of farmyard manure input compared to that at Chaffee could contribute to the difference. Farmyard manure application enhanced *SOC* storage [36]. Moreover at Finance the sugarcane is irrigated and a little amount of fertilizer was applied (**Table 1**). Fertilization and irrigation can enhance *SOC* by increasing the amount of aboveground biomass and root biomass [2]. Even if the management for aboveground biomass was similar, the root biomass can contribute for the *SOC* difference between the sites. Besides the management, at Finance, the low soil carbon of the adjacent maize land may explain the relative increase in *SOC* and soil *N* in the sugarcane.

4.4. Base Cations and CEC

Organic matter contributes significantly to the CEC of a soil and the high CEC of soils under shade coffee as compared with those soils under maize can be explained by the higher level of *SOC* under the shade coffee land use. In this study, the soil under sugarcane contained lower exchangeable K^+ when compared with annual maize land use. Such decrease in exchangeable K could be expected as sugarcane is a large K consumer [45].

5. Conclusion

In general, shade coffee land use stored more *SOC* as compared to adjacent maize, but khat and sugarcane land uses were less effective in *SOC* storage. The increased *SOC* in the shade coffee land use is attributed to increased litter input and reduced soil disturbance under shade coffee. The difference in relative *SOC* storage between shade coffees in different sites could be due to the difference in soil texture and the low level of *SOC* in the adjacent maize land use. Among perennials, shade coffee also has the potential to improve soil *N* stock as well. Soils under shade coffee had higher *N* stock than soils under adjacent maize, while soils under khat and sugarcanes had no difference from soils under maize. Improved soil *N* under shade coffee could be attributed to factor such as higher litter input, reduced leaching and *N*-uplift from the coffee plants and shade trees. Perennial shade coffee, khat and sugarcane land uses have generally shown little effect on the base cation concentrations of the soil over two decades. Hence, this finding has implications for selection of appropriate sustainable agricultural land use and land use suitable for climate change mitigation efforts.

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